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THE COMPUTATION OF THE BULK MODULI OF A SYNTHETIC HYDROCARBON HYDRAULIC FLUID

AIR FORCE MATERIALS LABORATORY

APRIL 1973

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F. C. BROOKS

TECHNICAL REPORT AFML-TR-73-81

APRIL 1973

AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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13 ABSTRACT

The bulk moduli of a synthetic hydrocarbon are calculated and appropriate equations are presented. Methods of determining and predicting bulk moduli are reviewed. A conservative low value of isothermal secant bulk modulus of the synthetic hydrocarbon candidate was selected from determinations produced with the Klaus apparatus. This selected value served as the primary datum point for calculating isothermal secant and tangent bulk moduli and adiabatic secant and tangent bulk moduli.

The results of these calculations are presented in tabular and graphical form for temperatures of 100, 200, 275, 300, 400 and 500 F and pressures between 0 and 5000 psig.

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BULK MODULUS						
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THE COMPUTATION OF THE BULK MODULI OF A SYNTHETIC HYDROCARBON HYDRAULIC FLUID

F. C. BROOKS

FOREWORD

This report was prepared by the Lubricants and Tribology Branch of the Nonmetallic Materials Division, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This effort was conducted under Project No. 7340, "Nonmetallic and Composite Materials," Task No. 734008, "Energy Transfer Fluids," with F. C. Brooks acting as Project Engineer.

This report presents the purpose and results of an effort expended between November 1972 and January 1973.

This technical report has been reviewed and is approved.

Kenneth A. Davis

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Chief
Lubricants and Tribology Branch
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ABSTRACT

The bulk moduli of a synthetic hydrocarbon are calculated and appropriate equations are presented. Methods of determining and predicting bulk moduli are reviewed. A conservative low value of isothermal secant bulk modulus of the synthetic hydrocarbon candidate was selected from determinations produced with the Klaus apparatus. This selected value served as the primary datum point for calculating isothermal secant and tangent bulk moduli and adiabatic secant and tangent bulk moduli.

The results of these calculations are presented in tabular and graphical form for temperatures of 100, 200, 275, 300, 400 and 500 F and pressures between 0 and 5000 psig.

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INTRODUCTION

Bulk modulus is one of the important engineering properties of a hydraulic fluid. Therefore it is advantageous that accurate, reliable bulk modulus values be distributed. It is the purpose of this effort to provide reliable values of isothermal and adiabatic secant and isothermal and adiabatic tangent bulk moduli of MIL-H-83282 hydraulic fluid for engineering and research applications.

Bulk modulus is the volumetric modulus of elasticity of a liquid, or simply, a measure of a liquid's spring rate. It is, therefore, the reciprocal of liquid compressibility.

Hydraulic fluid bulk moduli are used in hydraulic system and component design calculations to determine such factors as static and dynamic stiffness, resonant frequencies and pump characteristics. The kind of bulk modulus values which are used depends upon the factors which are being studied.

There are two common methods of determining bulk modulus. One is the pressure-volume-temperature (P-V-T) method which measures the isothermal secant bulk modulus of the test liquid. Klaus and associates (references 1, 2) have reported on the development of a direct reading apparatus which utilizes calibrated pycnometers housed in a high pressure glass windowed cell. Liquid densities may be determined to $\pm$ 0.2 percent of a pressure range of 0 to 10,000 psig. These measurements result in a precision of $\pm$ 0.5 percent when translated to bulk modulus.

The second common method of determining bulk modulus is the sonic method, which measures the velocity of sound in the liquid and determines the adiabatic tangent bulk modulus. Peeler and Green (Reference 3), and Noonan (Reference 4) have studied several hydraulic fluids using the sonic method of bulk modulus determination.

Wright (Reference 5) made a comprehensive study of bulk modulus determinations and proposed a method of predicting the bulk modulus of petroleum oils from their density. Wright notes that the bulk modulus determinations made by Klaus are in agreement with his findings.

The results of bulk modulus determinations of MIL-H-5606A hydraulic fluid, conducted by three investigators, are shown in Table I. The isothermal secant data, reported by investigator B, cannot be directly compared to the adiabatic tangent data reported by investigators A and C. By calculating adiabatic tangent bulk modulus from the isothermal secant values, the results of the three investigators, as shown in Figure 1, became comparable. The results of investigators A and B are in excellent agreement over the pressure range of 2000 to 5000 psig. The results reported by investigator C are approximately 21,000 psi less than investigator B's results, over the entire pressure range.

Klaus, Reference 6, presented a method for predicting the isothermal secant and isothermal tangent bulk moduli of several hydraulic fluid species. Over the 0 to 10,000 psig pressure range, the predicted values agree with experimental bulk modulus determinations within ± 2.0 percent. Predicted values of isothermal secant bulk modulus were related to ASME "Pressure-Viscosity Report" density results with an accuracy of ± 4.0 percent over a temperature range of 32 to 425 F and a pressure range of 0 to 150,000 psig.

The bulk moduli values computed during this program were obtained by reviewing the isothermal secant bulk modulus of four different samples of MIL-H-83282, which were measured with the Klaus apparatus, and selecting a conservative value as a starting point. From this starting point, isothermal secant and isothermal tangent bulk moduli values were calculated using the Klaus equations. These values were then used to calculate adiabatic tangent and secant bulk moduli values.

TABLE I

THE BULK MODULUS OF MIL-H-5606A HYDRAULIC FLUID

Temperature: 100 F

Pressure psig	Investigator A Adiabatic Tangent psi	Investigator B Isothermal Secant psi	Investigator C Adiabatic Tangent psi
1,000	235,000	191,000	220,300
2,000	254,000	196,500	233,800
3,000	268,000	202,000	245,400
4,000	279,000	207,500	258,400
5,000	291,000	213,000	270,200
10,000		240,500	

A COMPARISON OF BULK MODULUS

DETERMINATIONS BY THREE INVESTIGATORS

FLUID: MIL-H-5606A
TEMPERATURE: 100 F

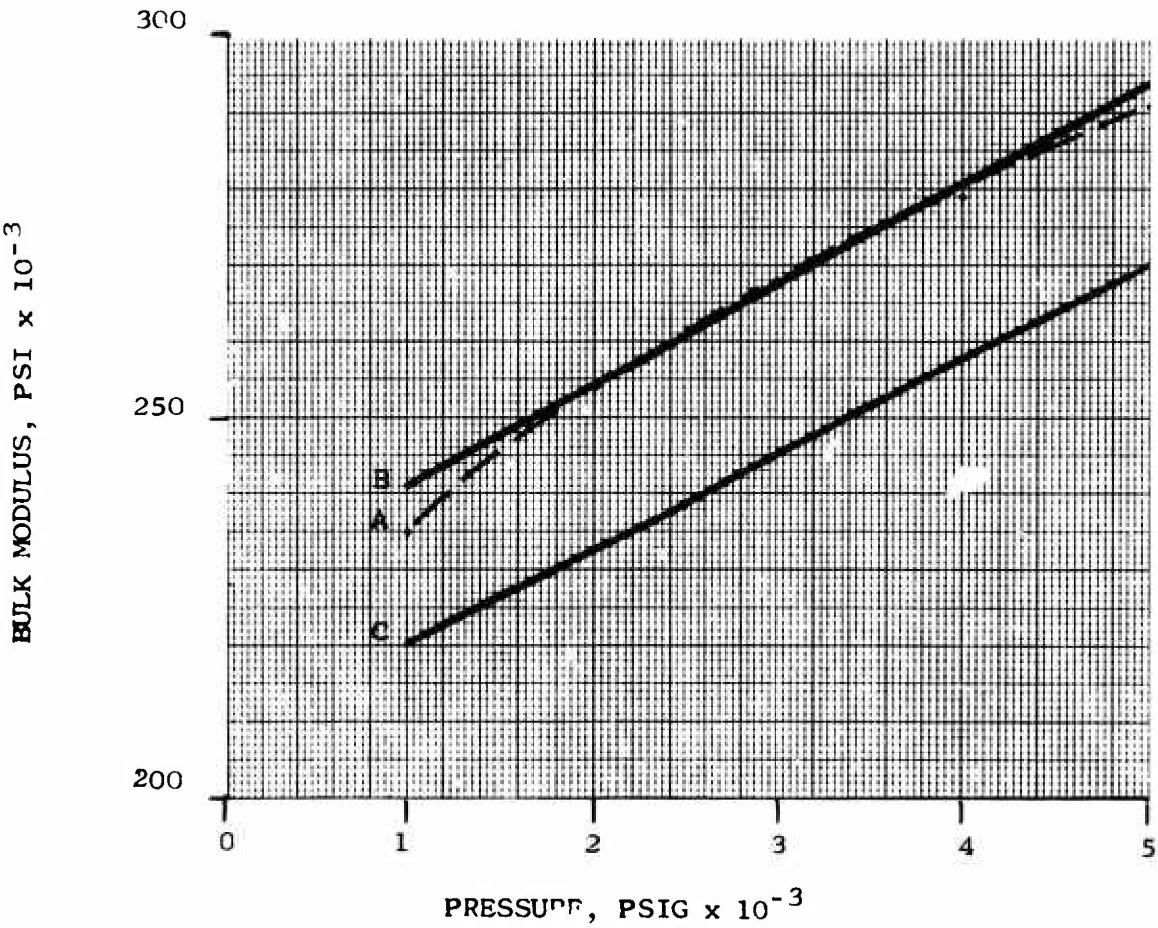

FIGURE 1

SECTION II

ISOTHERMAL SECANT BULK MODULUS OF MIL-H-83282

The isothermal secant bulk modulus of qualification samples of MIL-H-83282, as determined in the Klaus apparatus, were compared and a conservative low value was selected for the starting point of this effort. The value selected was 202,500 psi at 100 F and 2000 psig.

Using this datum point and equation (1), the isothermal secant bulk modulus at 100 F and 0 psig was calculated.

$$\left[\bar{B} = \bar{B}_o + 5.30\ P\right]_T \qquad (1)$$

where:

$\bar{B}$ = isothermal secant bulk modulus at pressure P and temperature T, expressed in pounds/square inch.

$\bar{B}_o$ = isothermal secant bulk modulus at 0 psig and temperature T, expressed in pounds/square inch.

P = pressure, in psig.

Using this calculated value $\bar{B}_o$ ad $\bar{B}_T$, at 0 psig and equation (2), values $\bar{B}_o$ were calculated for temperatures of 200, 275, 300, 400 and 500 F.

$$\left[\log \frac{\bar{B}_{T_1}}{\bar{B}_{T_2}} = \beta\ (T_2 - T_1)\right]_P \qquad (2)$$

where:

$\bar{B}_{T_1}$ = isothermal secant bulk modulus at pressure P and temperature T_1, ^oF, and

$\bar{B}_{T_2}$ = isothermal secant bulk modulus at pressure P and temperature T_2, F.

Values of β, a generalized relationship of the slope as a function of pressure, are presented in Figure 6.

Using the calculated values of $\bar{B}_o$, at temperatures of 100, 200, 275,

300, 400 and 500 F, and equation (1), a complete set of values of $\overline{B}$ were calculated for pressures of 1000, 2000, 3000, 4000, 5000, 6000, 8000, and 10,000 psig. The results of these calculations are shown in Table II, and, for easy access of intermediate pressure values, is presented graphically to 5000 psig in Figure 2.

TABLE II

ISOTHERMAL SECANT BULK MODULUS OF MIL-H-83282

Pressure psig	100 F	200 F	275 F	300 F	400 F	500 F
0	191,900	139,000	107,800	100,700	73,000	52,900
1,000	197,200	144,300	113,100	106,000	78,300	58,200
2,000	202,500	149,600	118,400	111,300	83,600	63,500
3,000	207,800	154,900	123,700	115,600	88,900	68,800
4,000	213,100	160,200	129,000	121,900	94,200	74,100
5,000	218,400	165,500	134,300	127,200	99,500	79,400
6,000	223,700	170,800	139,600	132,500	104,800	84,700
8,000	234,300	181,400	150,200	143,100	115,400	95,300
10,000	244,900	192,000	160,800	152,700	126,000	105,900

All bulk modulus values expressed in psi.

ISOTHERMAL SECANT BULK MODULUS OF MIL-H-83282

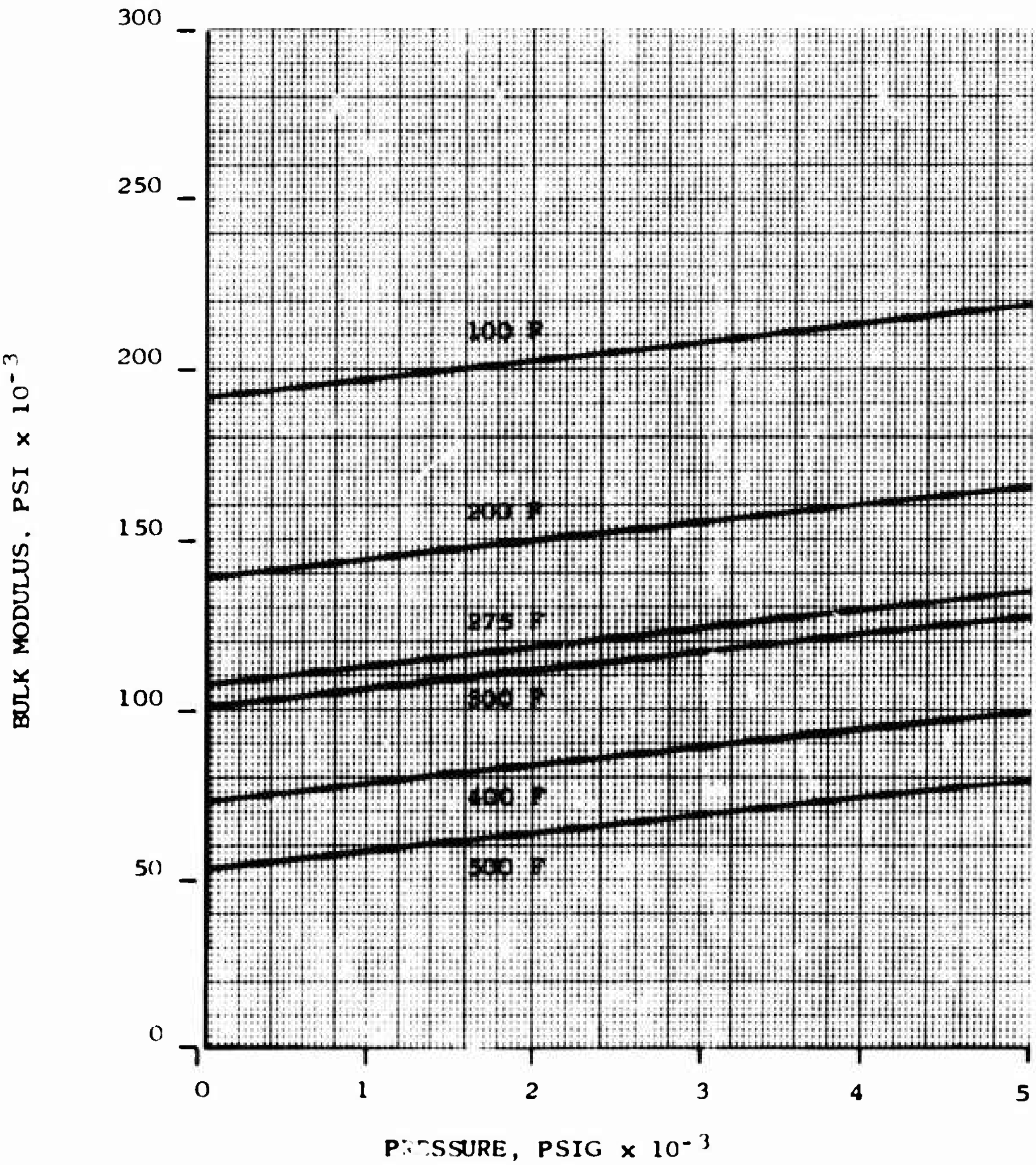

FIGURE 2

SECTION III

THE ISOTHERMAL TANGENT BULK MODULUS OF MIL-H-83282

The isothermal tangent bulk modulus of MIL-H-83282 was calculated for temperatures of 100, 200, 275, 300, 400 and 500 F at pressures of 1000, 2000, 3000, 4000 and 5000 psig using the previously calculated values of $\overline{B}$ and equation (3).

$$(B_R)_P = \overline{B}_{2P} \qquad (3)$$

where:

$(B_R)_P$ = isothermal tangent bulk modulus at temperature T and pressure P, and

$\overline{B}_{2P}$ = isothermal secant bulk modulus at temperature T and twice pressure P.

The results of these calculations are shown in Table III and are presented graphically in Figure 3.

TABLE III

ISOTHERMAL TANGENT BULK MODULUS OF MIL-H-83282

Pressure psig	100 F	200 F	275 F	300 F	400 F	500 F
0	191,900	139,000	107,800	100,700	73,000	52,900
1,000	202,500	149,600	118,400	111,300	83,600	63,500
2,000	213,100	160,200	129,000	121,900	94,200	74,100
3,000	223,700	170,800	139,600	132,500	104,800	84,700
4,000	234,300	181,400	150,200	143,100	115,400	95,300
5,000	244,900	192,000	160,800	153,700	126,000	105,900

All bulk modulus values expressed in psi.

ISOTHERMAL TANGENT BULK MODULUS OF MIL-H-83282

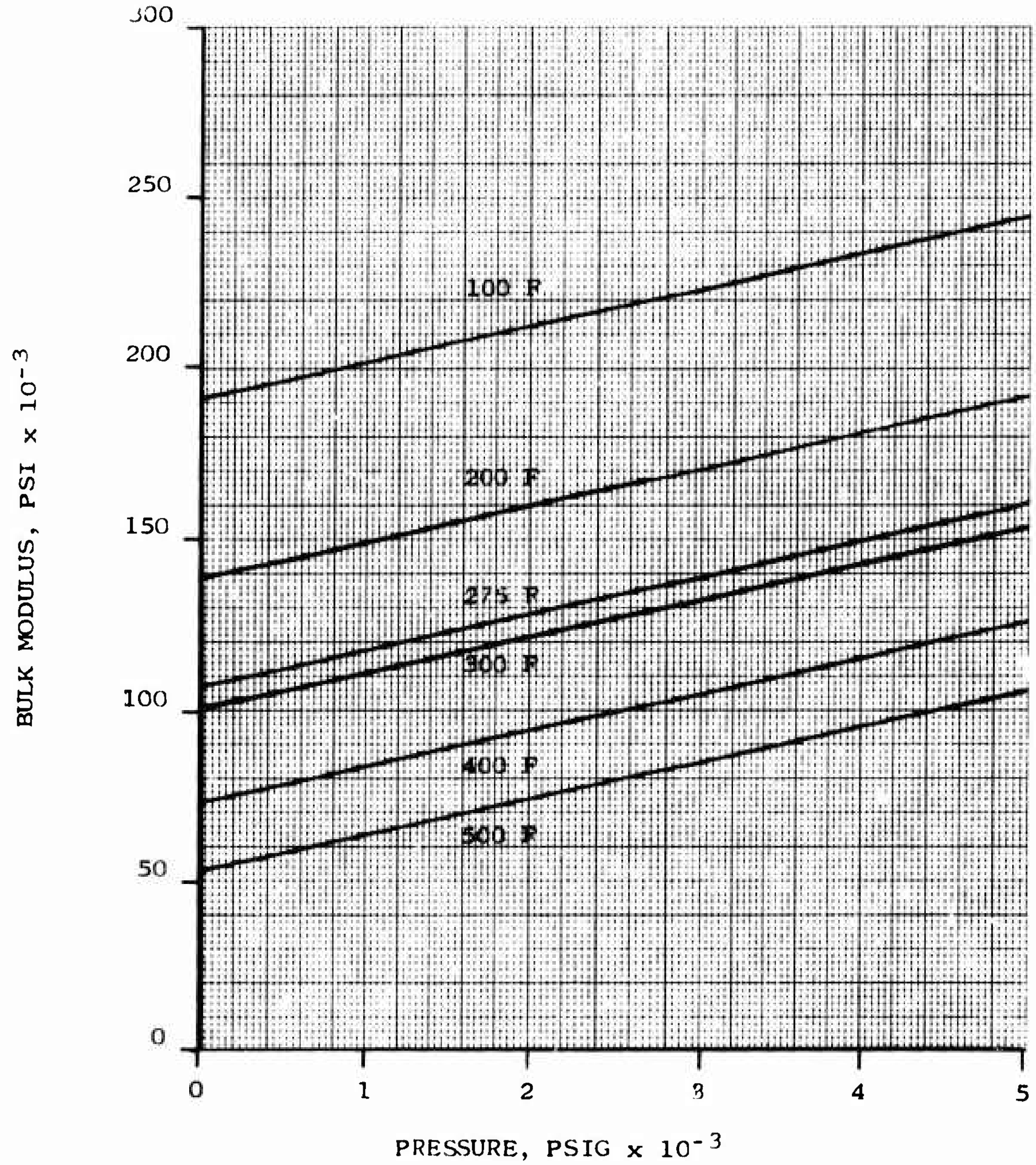

FIGURE 3

SECTION IV

THE ADIABATIC TANGENT BULK MODULUS OF MIL-H-83282

The relationship between adiabatic and isothermal tangent bulk modulus may be expressed by equation (4).

$$\frac{B_S}{B_R} = \gamma = \frac{C_P}{C_V} \tag{4}$$

where:

B_S = adiabatic tangent bulk modulus at temperature T and pressure P,

B_R = isothermal tangent bulk modulus at temperature T and pressure P,

C_P = specific heat at constant pressure,

C_V = specific heat at constant volume,

γ = ratio of specific heats or bulk moduli.

The adiabatic tangent bulk modulus of MIL-H-83282 was calculated by using the previously calculated values of isothermal tangent bulk modulus and equation (4). Values of γ, which are presented in Figure 4, were determined for hydraulic fluid MIL-H-5606A. However, these data are considered applicable to calculations for typical mineral oil base fluids (references 3 and 6).

The results of these calculations are shown in Table IV and are presented graphically in Figure 4.

TABLE IV

ADIABATIC TANGENT BULK MODULUS OF MIL-H-83282

Pressure psig	100 F	200 F	275 F	300 F	400 F	500 F
0	236.000	165,400	125,000	115,800	81,000	56,600
1,000	249.100	178,000	137,300	128,000	92,800	67,900
2,000	262,100	190,600	149,600	140,200	104,600	79,300
3,000	275,200	203,300	161,900	152,400	116.300	90,600
4,000	288,200	215,900	174,200	164,600	128,100	102,000
5,000	301,200	228,500	186,500	176,800	139,900	113,300

All bulk modulus values expressed in psi.

ADIABATIC TANGENT BULK MODULUS OF MIL-H-83282

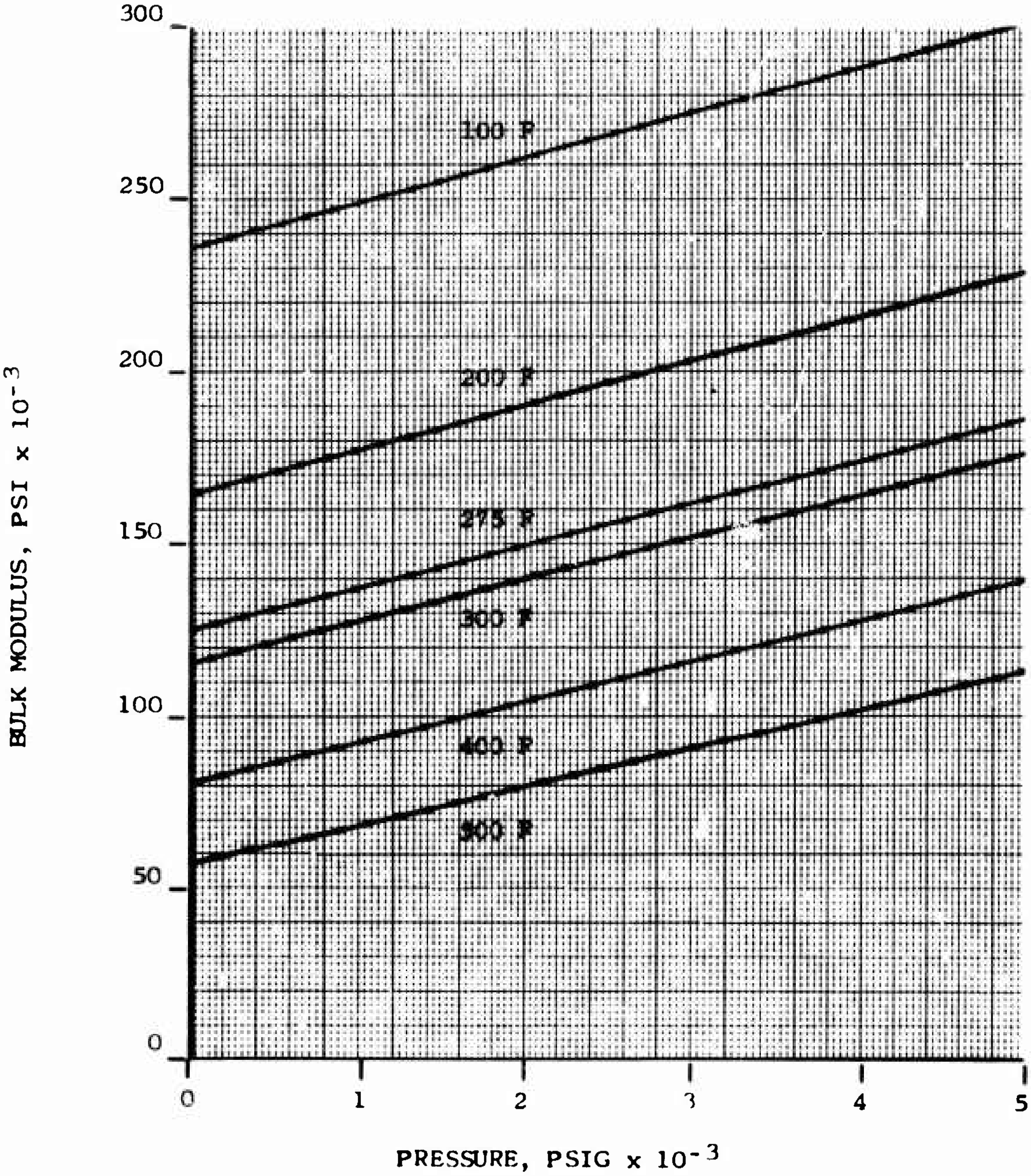

FIGURE 4

SECTION V

ADIABATIC SECANT BULK MODULUS OF MIL-H-83282

The adiabatic secant bulk modulus of MIL-H-83282 was calculated by using the previously calculated adiabatic tangent bulk modulus values and equation (5).

$$B_B = \frac{B_{R_o} + B_R}{2} \qquad (5)$$

where:

B_B = adiabatic secant bulk modulus at temperature T and pressure P,

B_{R_o} = adiabatic tangent bulk modulus at temperature T and 0 psig, and

B_R = adiabatic tangent bulk modulus at temperature T and pressure P.

The results of these calculations are shown in Table V and are presented graphically in Figure 5.

TABLE V

ADIABATIC SECANT BULK MODULUS OF MIL-H-83282

Pressure psig	100 F	200 F	275 F	300 F	400 F	500 F
0	236,000	165,400	125,000	115,800	81,000	56,600
1,000	242,600	171,700	131,200	121,900	86,900	62,300
2,000	249,100	178,000	137,300	128,000	92,800	68,000
3,000	255,600	184,400	143,500	134,100	98,700	73,600
4,000	262,100	190,700	149,600	140,200	104,600	79,300
5,000	268,600	197,000	155,800	146,300	110,500	85,000

All bulk modulus values expressed in psi.

ADIABATIC SECANT BULK MODULUS OF MIL-H-83282

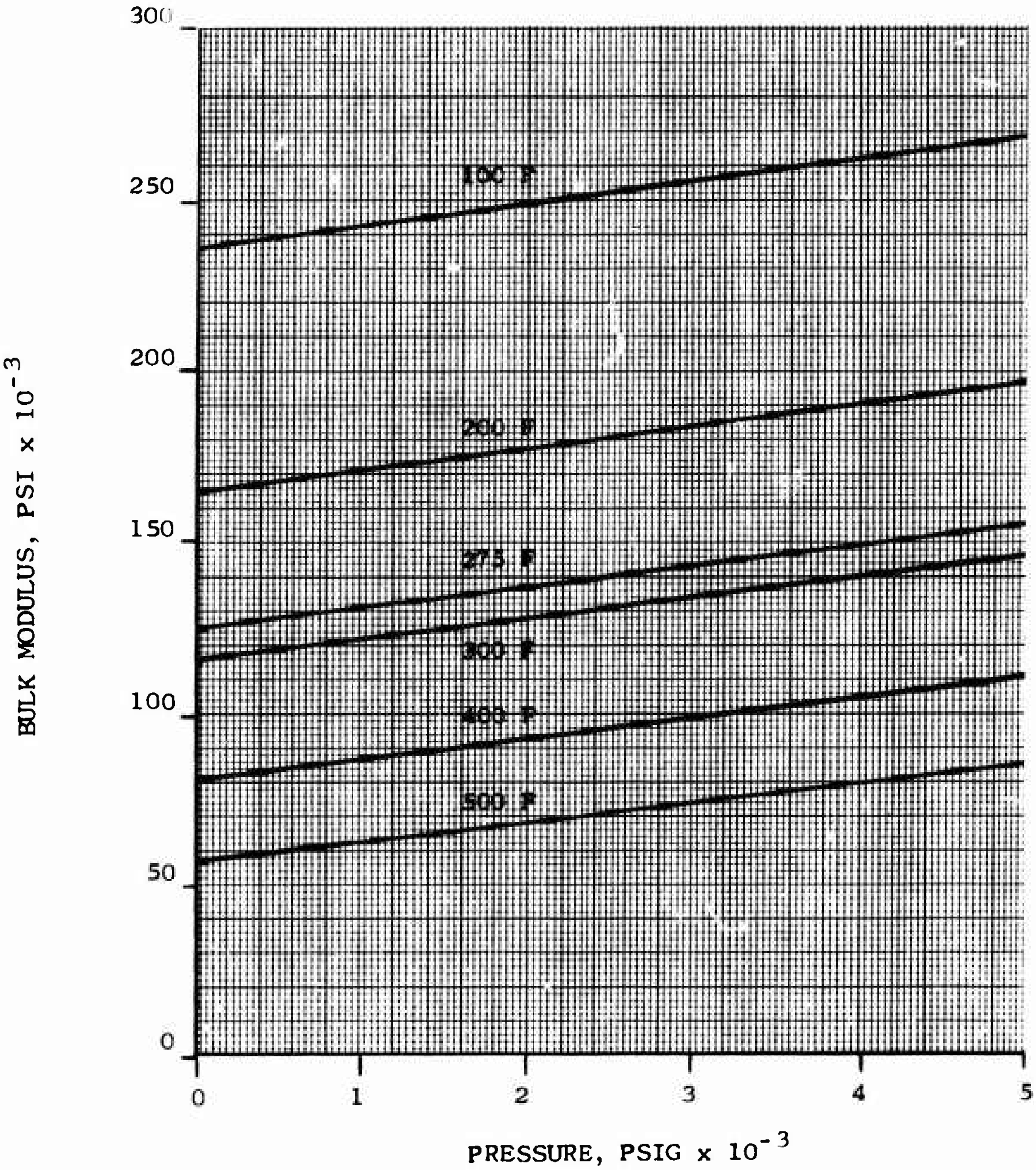

FIGURE 5

BETA AS A FUNCTION OF PRESSURE

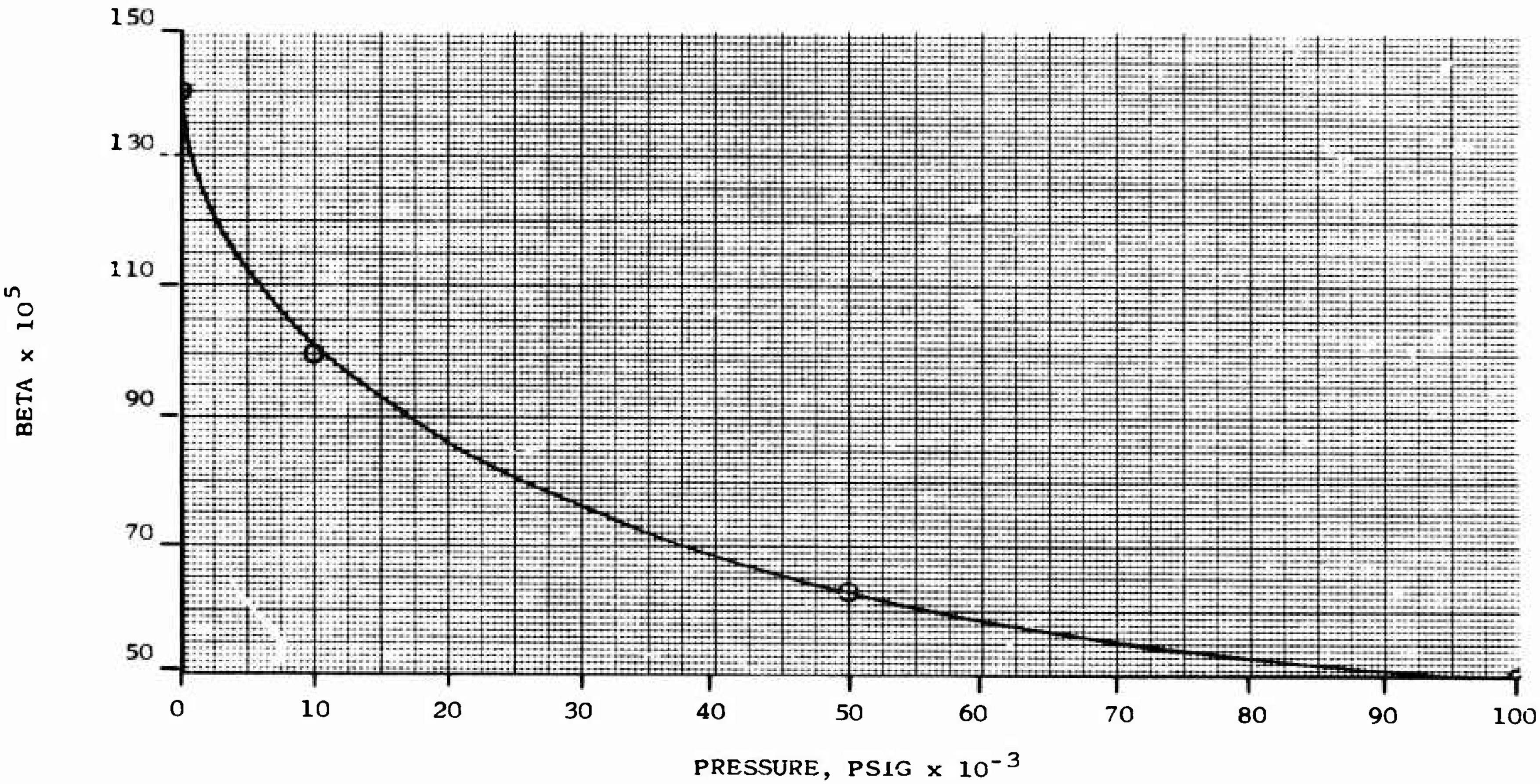

FIGURE 6

GAMMA AS A FUNCTION OF TEMPERATURE

FOR MIL-H-5606A HYDRAULIC FLUID

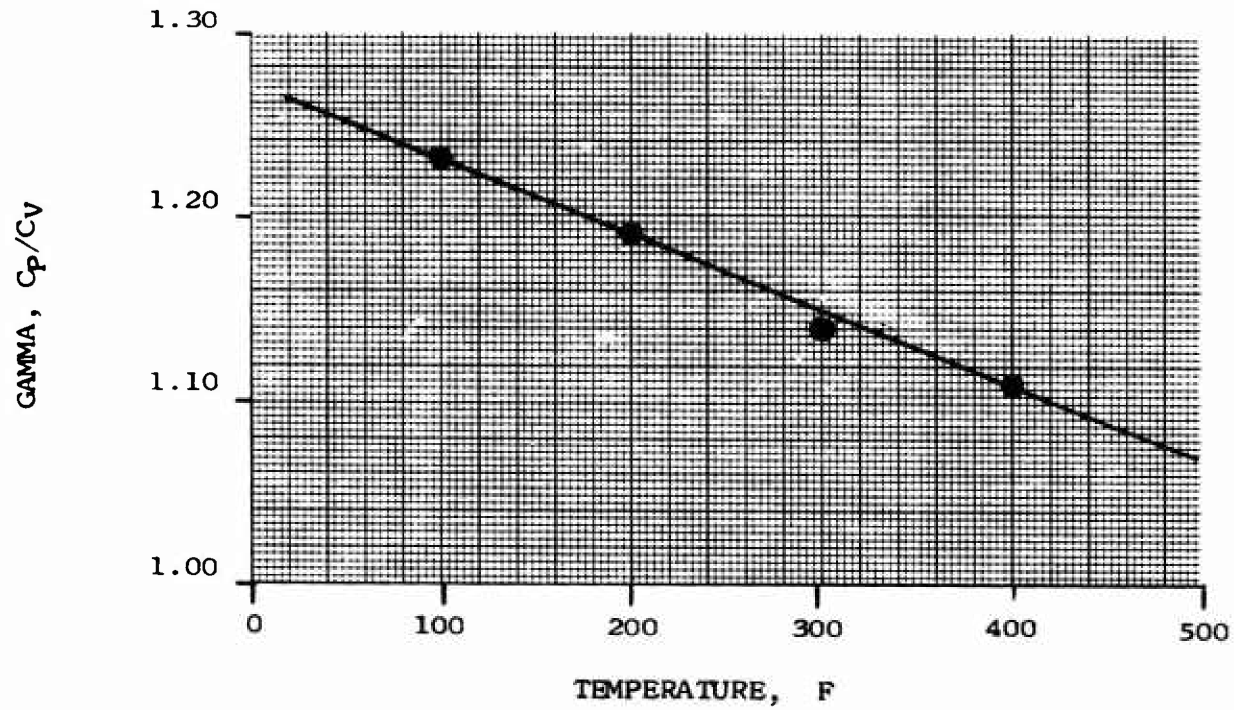

FIGURE 7

SECTION VI

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